DEVELOPMENT OF A NOVEL MICROWAVE RADAR SYSTEM USING ANGULAR CORRELATION FOR THE DETECTION OF BURIED OBJECTS IN SANDY SOILS

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LONG-TERM GOAL

Our long-term goal is to study the properties of angular correlation function (ACF) of random scattering and apply ACF in the detection of buried objects in sandy soil and other clutter.

SCIENTIFIC OBJECTIVES

Random media (rough surfaces, discrete scatterers, and inhomogeneities) scattering has been studied extensively by the calculation and measurement of radar cross section (RCS). For a target embedded in clutter, both the target and clutter contribute to the received signal. It is difficult to separate the target signal from the clutter by using RCS. Angular correlation function (ACF) is the correlation of two scattered fields in directions $\vec{k}_{s1}$ and $\vec{k}_{s2}$ corresponding to two incident waves in directions $\vec{k}_{i1}$ and $\vec{k}_{i2}$. An important property of ACF of random scattering is called "memory effect". It says the clutter contribution to ACF is strong only on specific combinations of incident and scattered directions. The ACF due to clutter is small if the "memory effect" and those angular correlations are avoided. Therefore, ACF can be used in target detection and target imaging.

APPROACH

We illustrate and test the ACF method based on Monte Carlo simulations and experiment. The SAR data is used for image processing by calculating field and ACF with focusing on desired positions. As shown in (Zhang & Tsang, 1997) the image processing with focusing can be understood as the calculation of wave statistics (field, ACF) by spectral averaging. In correlation imaging, the "memory effect'' of the angular correlation function is avoided so that clutter scattering is minimized.

WORK COMPLETED

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1. *Numerical simulations:*
   In the simulations, the clutter is modeled by 80,000 randomly distributed small scatterers. The scattering amplitudes of each target and each scatterer are calculated based on Mie scattering. The total scattered fields (simulated SAR data) are calculated based on coherent addition approximation for many frequencies and angles. The configuration is that of circular SAR as shown in Figure 1. The scattered fields (simulated SAR data) are used for image processing. Both conventional SAR (field) imaging and angular correlation (ACF) imaging have been used to process the data, and comparisons are made. Frequency angular correlation (FACF) imaging has also been used in a linear SAR system; and

2. *Experiment:*
   We have developed a very flexible scanning system to study ACF and SAR processing in the circular geometry. Unlike our previous study of ACF which was obtained as a function of scattering angle, the ACF in the circular geometry is evaluated from the azimuthal angular scan and it can be easily implemented with the airborne radar. In addition, this new method can be combined with the circular SAR technique which has been studied by the Navy (NCCOSC, San Diego). The new system consists of two motor-controlled 2 meter diameter disks on which transmitting and receiving antennas are mounted. Each antenna can be moved in the azimuth direction from 0 to 360 degrees. The circular SAR data processing is applied to reconstruct 3-D target images. As an example, the circular SAR images of spheres obtained at different depth (a, b, c, and d), are shown in Figure 2. We have also derived a method to combine circular SAR and ACF.

   Currently, all practical SAR systems use a linear flight path (straight line), and a viewing angle is limited to 20 to 30 degrees which makes ACF processing difficult. However, if a spotlight mode is used during the flight path, the viewing angle can be increased up to 90 degrees and the ACF processing can be combined with the linear SAR. We have studied the ACF processing with a spotlight mode linear SAR operating at X-band. Figure 3 shows a schematic diagram of the experimental setup and SAR images obtained with the traditional SAR processing and ACF processing.

RESULTS

The numerical results show that the ACF method has advantages over the conventional methods. A strong correlation of ACF is only exhibited on the memory line for rough surface scattering and memory dots for volume scattering. That is a result of translational invariance of random scattering. Consequently, correlation imaging has an improvement over the conventional field imaging. In Figures 4 and 5, we show results of imaging using circular SAR. The result of the conventional field imaging is shown in Figure 4. Our new result based on ACF imaging is shown in Figure 5. The visibility for ACF imaging of Figure 5 is twice that of field imaging in Figure 4. The spreading due to the frequency dependence is overcome in ACF imaging.

We have obtained preliminary experimental data with the X-band radar system to detect target embedded in geophysical media in the circular geometry. The studied geophysical media are gravel of various sizes and sand. This image is shown in Figure 6.

IMPACT/APPLICATION

The study gives deeper understanding of the mechanisms of wave scattering by random media and the interaction between targets and clutter. The principle of imaging is generalized. The method developed in this project will be used to improve the data processing methods in remote sensing and imaging.

TRANSITIONS

Our method and software are available for use in real SAR systems for ACF processing and imaging processing.

RELATED PROJECTS

The following is an ongoing research project supporting PI Leung Tsang:

"Microwave remote sensing of earth terrain" sponsored by National Science Foundation. In the project, we conduct research on analytical and numerical methods of rough surface scattering and random media scattering. The results are applied to remote sensing of soils, snow, and vegetation.

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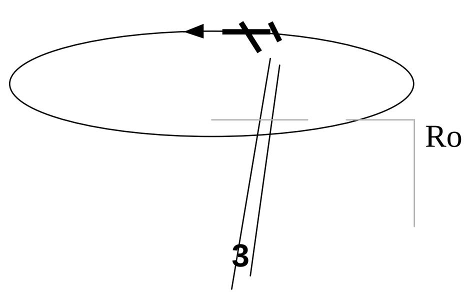


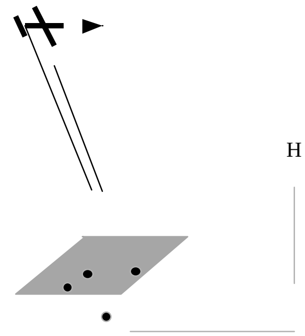
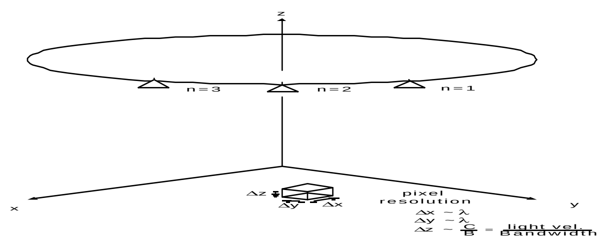


Figure 1. Configuration of Circular SAR for ACF Imaging.
Confocal Circular SAR Resolution



Generalized ambiguity function in x-, y- and z-directions
Bandwidth: 7-13 GHz, Depression angle: θ_{dp}=45^{o}, Antenna height: 1m

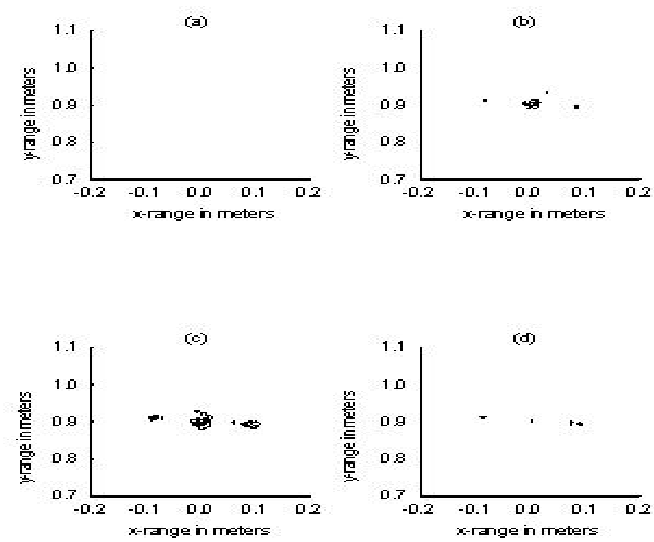


Figure 2. CSAR Data

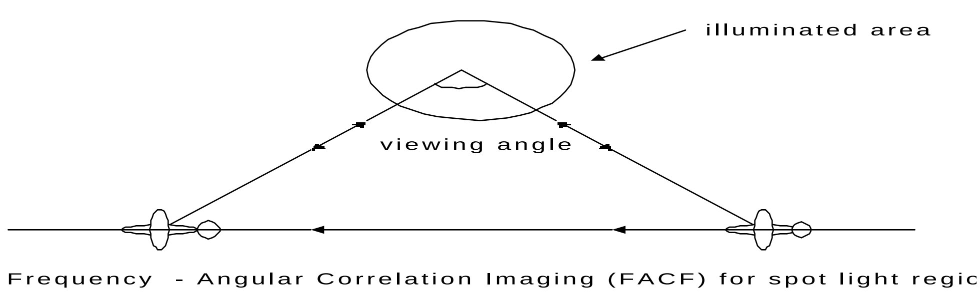


Figure 3. LSAR/ ACF Extension to Linear SAR (spotlight mode)

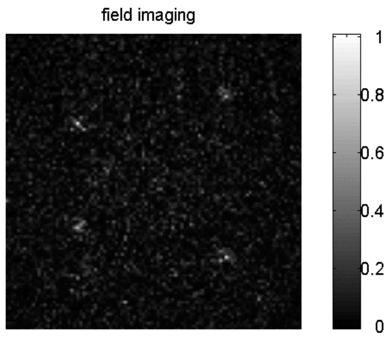


Figure 4. Simulated Image of Targets Embedded in Clutter by Conventional Field Imaging.

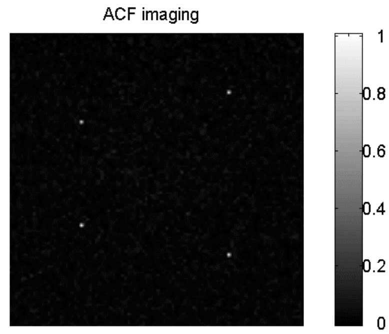


Figure 5. Simulated Image of Targets Embedded in Clutter by ACF Imaging.

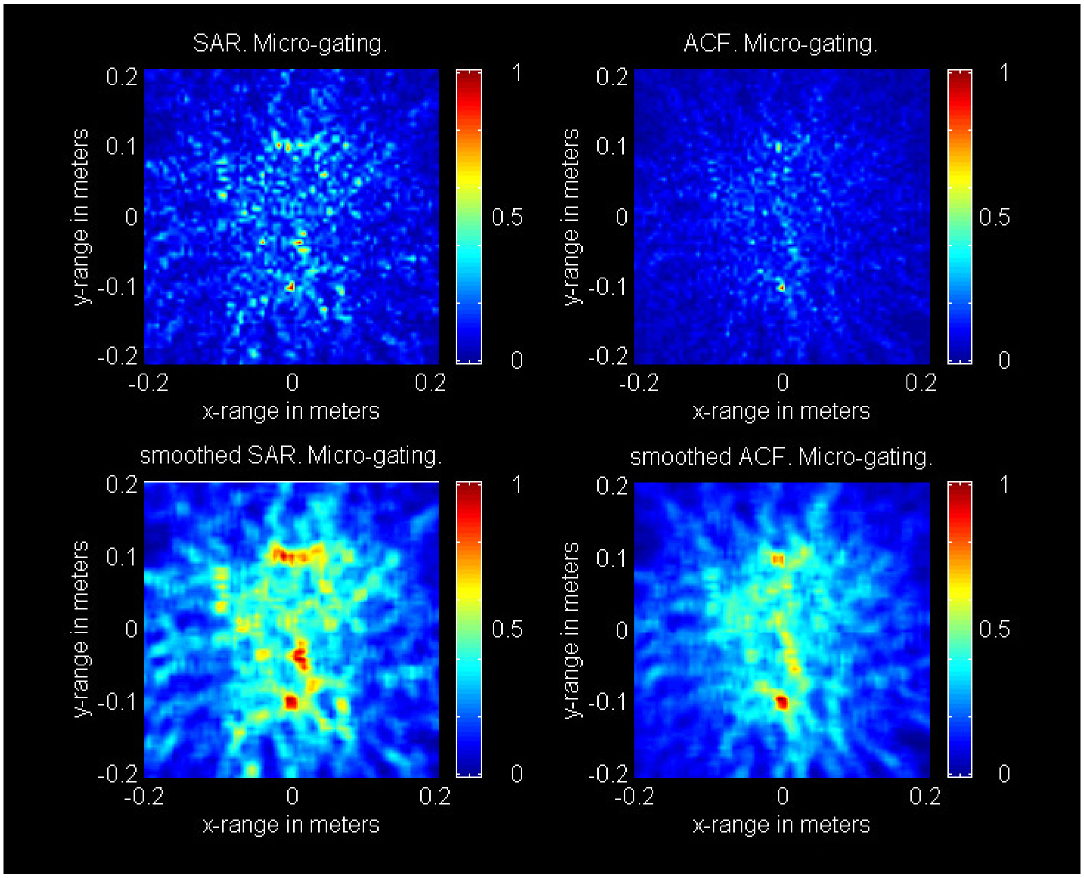


Figure 6. Images of Two Spheres on Gravel. Left side: SAR Images, Right side: ACF Images.